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March 08, 2004

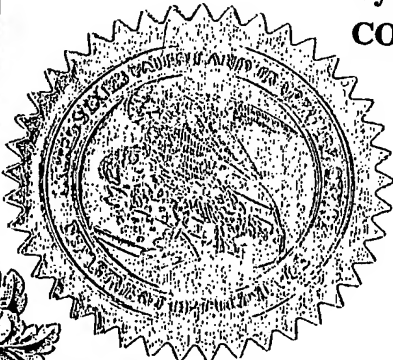
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APPLICATION NUMBER: 60/458,442

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PTO/SB/16 (6-95)  
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# PROVISIONAL APPLICATION COVER SHEET

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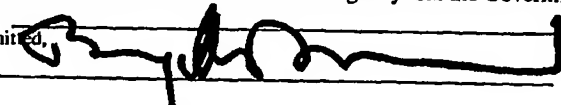
Docket Number		1497-119		Type a plus sign (+) inside this box →
INVENTOR(S)/APPLICANT(S)				
LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)	
ROSIN	Tomas		Turku, Finland	
TITLE OF THE INVENTION (280 characters)				
METHOD FOR AIR/FUEL CONTROL AND FOR SOOT CLEANING OPTIMIZATION				
CORRESPONDENCE ADDRESS				
Direct all correspondence to:				
<input checked="" type="checkbox"/>	Customer Number:	23117	Place Customer Number Bar Label Here →	
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ENCLOSED APPLICATION PARTS (check all that apply)				
<input checked="" type="checkbox"/>	Specification and claims	Number of Pages	11	<input checked="" type="checkbox"/> Applicant claims "small entity" status.
<input checked="" type="checkbox"/>	Drawing(s)	Number of Sheets	4	<input type="checkbox"/> "Small entity" statement attached.
			<input checked="" type="checkbox"/> Other (specify)	2 claims
METHOD OF PAYMENT (check one)				
<input checked="" type="checkbox"/>	A check or money order is enclosed to cover the Provisional filing fees (\$80.00)/(\$80.00)			PROVISIONAL FILING FEE AMOUNT (\$)
<input checked="" type="checkbox"/>	The commissioner is hereby authorized to charge filing fees and credit Deposit Account Number			80.00
		14-1140		

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 60458442

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☒ No.  
☐ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,  
 SIGNATURE



DATE

March 31, 2003

TYPED or PRINTED NAME

Bryan H. Davidson

REGISTRATION NO.  
 (if appropriate)

30,251

☐ Additional inventors are being named on separately numbered sheets attached hereto.

## PROVISIONAL APPLICATION FILING ONLY

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Our Ref.: 1497-119

# ***U.S. PROVISIONAL PATENT APPLICATION***

***Inventor(s):*** Tomas ROSIN

***Invention:*** METHOD FOR AIR/FUEL CONTROL AND FOR SOOT CLEANING  
OPTIMIZATION

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## ***SPECIFICATION***

## Method for air/fuel control and for soot cleaning optimization

### FIELD OF THE INVENTION

The present invention relates generally to process industry, such as power plants. More particularly, the present invention relates to a method for air/ fuel control. Furthermore the present invention relates to a method for optimizing of cleaning particles or fouling from surfaces of the process system.

### BACKGROUND OF THE INVENTION

It has been known for a long time that maintaining the stoichiometric ratio between air and fuel in a pulverized fuel fired process is an important criterion to minimize emissions such as  $\text{NO}_x$  and CO. For example, a pulverized coal (PC) boiler constitutes a large number of burners. It has been both observed and proved that the stoichiometric ratio between air and fuel has to be maintained on a per burner basis. Therefore, both the fuel flow and the airflow are measured, and either the airflow or the fuel flow is used as the control variable, to keep the ratio between the fuel flow and the airflow for each individual burner within strict limits.

It has been proved that matching the airflow to the fuel flow for each individual burner reduces emissions as well as improves other variables in the operation of a solid fuel fired boiler. However, it has been identified that only matching the airflow and the fuel flow does not provide the minimum emission level for the  $\text{NO}_x$ , CO and other adjacent emissions.

The typical and current air/fuel balancing concept has been described in the scheme of figure 1. As illustrated in figure 1, typical air/fuel balancing method is based on air flow and coal flow measurements for each individual burner. Please note, that the total amount of air is matched with the total amount of fuel by keeping the  $\text{O}_2$  concentration in the exhaust gas on a certain level (e.g. 2%). The

point of the known optimization methods is to keep the same share of fuel and air on each burner. If one burner carries a higher amount of fuel, a higher amount of air should be distributed to that burner. That is, the percent fuel and the percent air on one burner should be the same. However, now it has been surprisingly observed that occasionally either more or less air than the stoichiometric ratio would suggest, is needed for a certain burner in order to minimize the emissions. The reason for this phenomenon is unknown, but has most likely a connection to the mixing properties of the fuel and air in the flame. Therefore, a need exists in the industry for a method of optimizing air/fuel ratio wherein optimization will be made more efficiently being based on the measurements of the actual process conditions.

The present invention relates further to soot cleaning optimization. Minimizing of emissions such as NO<sub>x</sub>, decreases also the need for sooting. Cleaning particles (fouling) from surfaces is a routine that is fairly common in the process industry. For example, when running a combustion process it is essential to keep heat exchanger surfaces clean for the sake of efficiency. Many different kinds of soot cleaners (blowers) are used and they are run according to a certain sequence to keep the heat exchange surfaces as clean as possible. It should be noticed that running soot cleaners is expensive. However, high expenses will emerge as well if soot cleaners are not used at all. Therefore, it is of great importance to optimize the soot cleaning process thoroughly.

It should be noticed that cleaning heat exchanger tubes with steam, without any particle (soot in this case) layer on their surfaces, is very eroding for the walls of these tubes. Erosion of the heat exchanger tubes is again a very expensive affair.

Typically the need for the soot cleaning is estimated from raised exhaust gas temperatures and possible steam temperature anomalies. This information does not necessarily give the precise information about which heat exchanger tubes has the most part of the soot stuck to its surface and which tubes are fairly clean.

Therefore, a need exists in the industry for a method of optimizing soot cleaning whereby the soot cleaning will be made more economically and efficiently being based on the measurements of the actual process conditions.

#### SUMMARY OF THE INVENTION

It is an object of the invention is to provide a method for air/ fuel control wherein at least one of the group of primary airflow, mill parameters, and secondary airflow,

is controlled using a control algorithm, which is determined by correlation analysis between ECT signals and the output and input signals of the process in order to detect dependencies, and by fuzzy modeling of the dependencies.

Furthermore, an another object of the invention is to provide a soot cleaning optimization method to be used in a process industry in which information on a sequence of a cleaning, time between running, etc. variables for cleaning devices are optimized based on the measurement of the particles entrained in the gas stream of the process. The measurement is based on detecting static electricity and/or change thereof in the gas stream of the process.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of an example and is not limited in the accompanying figures, in which alike references indicate similar elements, and in which;

- FIG. 1 illustrates schematically an air/fuel balancing concept according to the prior art,
- FIG. 2 illustrates schematically a flow scheme of correlation analysis according to the present invention,
- FIG. 3 illustrates schematically a fuzzy modeling algorithm according to the present invention,

- FIG. 4 illustrates schematically an implementation of a control system according to the present invention,
- FIG. 5 illustrates a schematic embodiment of an arrangement according to the present invention, and
- FIG. 6 illustrates a block scheme of an optimization according to the present invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Generally, the first aspect of the invention provides a method for air/ fuel control in burners, such as pulverized coal boiler, based on a measurement of a flow of particles for a suspension of gas and solids. The measurement can be used e.g. by using the measurement system disclosed in the applicant's earlier patent publication US 6,031,378 and/or the method disclosed in the applicant's earlier patent publication WO02/06775. The measurement system (Electric Charge Transfer System, ECT-system), disclosed in the above mentioned patent publications, is able to measure e.g. the velocity and the mass flow of particles for a suspension of gas and solids. The ECT measurement is of a local character, that is, the signal caused by the flowing particles is a function of distance from the particles to the ECT antenna. Therefore, a big duct requires use of many ECT antennas. It should be noticed that the particles entrained in the gas flow are not necessarily evenly distributed over the whole duct. Using several antennas will ensure that the particle flow is sensed properly over the whole duct, even though the rope of the particles would change its coordinates. Please note that a not even distribution of ash particles in the exhaust duct contains also a lot of valuable information.

The ECT system measures the state of the two-phase flow in burner ducts. The ECT measurement splits the raw signal (ECT LF signal) into AC and DC components. DC component is the spectral line for  $\sim 0$  Hz (mean value). Normal AC is the standard deviation of the raw signal on the frequency band 0.3-15 Hz.

The ECT velocity measurement collects measurement signals with a high sampling frequency (22 kHz). Fans and compressors as well as the combustion process (flame) cause pressure gradients in the gas flow. These gradients can be seen as intensified spectral density on different frequencies on the raw signal (ECT HF signal).

It has been observed that some patterns in the above mentioned ECT signals correlate with the readings from the emission metering devices of the boiler. The ECT measurement will provide information whether more or less air is needed than the stoichiometric ratio between fuel and air would suggest. The methodology to determine the optimal dosing of air for a burner is explained in more detail below.

The ECT signals (HF and LF) mirror the flow properties in the burner ducts. These flow properties depend on the process variables such as particle size, mass flow, particle velocity, and the flame properties (flame properties affect mainly the ECT HF signals). Dependency between the ECT signals and the output signals (NO<sub>x</sub>, CO, O<sub>2</sub>, airflow measurements, etc.) is estimated with different methods. The following methods can be used: correlation analysis, spectral analysis and fuzzy modeling. The result will be a dependency matrix showing which burner(s) has the strongest connection to the emission rates (e.g. NO<sub>x</sub> and CO).

The correlation analysis will typically build up large correlation matrixes between the ECT variables for the different burners as well as between the ECT variables of burners and the output variables (NO<sub>x</sub>, CO, O<sub>2</sub>, etc.). The size of the matrixes can be reduced significantly by eliminating such ECT signals that have strong correlation to a chosen ECT signal. In order to reduce the size of the matrix, a loop between 1 and n (number of burner pipes) is established where j expresses the reference burner pipe and k is the burner pipe against which the correlation is checked. If the correlation is strong enough between the ECT



signals of the pipe j and the pipe k, the pipe k can be eliminated from the matrix due to the fact that the ECT signals for the pipe k is represented in the ECT signals in the pipe j because of the strong correlation. This method will reduce the size of the matrixes and would also make it possible to group different burner pipes according to their internal correlation. Please see the flow scheme illustrated in figure 2 (R shows the correlation).

Spectral analysis is applicable only on signals that have a well-defined sampling rate. This is not the case for many of the output measurements used in prior art methods, which are based on the principle of taking a sample and analyzing it offline. Also time of update for these measurements can be even a few minutes.

The most potential signal for spectral analysis purposes is the ECT HF signal for each pipe because this signal type reflects well the state of the flame. Please note that two individual channels are used for each pipe to get the particle velocity. The flame impacts the ECT HF signals strongly besides the fans that transport the gas into the boiler as well as out from the boiler.

The spectral analysis will divide the ECT HF signals into different bands and determine which of the bands are correlating with the flame quality, and which of the bands are also related to other variables such as particle size, mass flow of the coal etc. The standard deviation will be calculated for each band and stored as a variable in a matrix.

When the ECT-system is used, there are a lot of signals available with different properties. The key issue is to be able to determine the dependency between these signals in a reliable and simple way. Fuzzy logic rules fulfill these criteria. The noise has to be removed from the signal without losing any relevant information in the signal. The algorithm works roughly as illustrated in figure 3 for each measurement vector.

The air/fuel control method according to the present invention can favorably be added on top of the air to fuel balancing in order to gain more reduction in the emissions. The control variables that can be used are fairly limited. The main control variables to affect the process are as follows: primary airflow (PA), mill parameters (separator settings, etc.) and secondary airflow (SA).

Please note that the role of the primary airflow is to transport the coal to the furnace, and the primary air should usually be kept as low as possible. Therefore, this variable does not usually offer much controllability, but the primary air should be high enough to provide a proper transport of the coal.

Mill parameters such as separator settings etc. are important in order to keep the particle size of the coal as small as possible and the flow as steady as possible. However, there are only static classifiers (separators) on many plants, which limits the use of the separator settings as a control variable. It should be noticed that the steady flow of the fuel and a small particle size are essential for an optimal combustion.

The most favorable variable to be used for minimizing the emissions is usually the secondary air (SA). The SA has a great impact on the flame, and hence, also impacts the ECT HF signals strongly. The block scheme as illustrated in figure 4 shows the control structure roughly.

Generally, the second aspect of the present invention provides an optimized soot cleaning process based on a measurement of a mass flow of particles for a suspension of gas and solids. The measurement can be used e.g. by using the measurement system disclosed in the applicant's earlier patent publication US 6,031,378 and/or the method disclosed in the applicant's earlier patent publication WO02/06775. Other suitable measuring systems are for e.g. other electrical measuring systems and optical analyzing systems. The soot cleaning optimization method can be utilized also independently in processes in which

method for air/ fuel control according to the first aspect of the invention is not used.

When the soot cleaning (particle cleaning) is in operation there will be more particles entrained in the gas stream than normally. The increase in the concentration of the particles will be calculated based on the increase in the ECT reading during the soot cleaning. Please see the illustration in fig 5 describing the arrangement. It should be noted, that the soot cleaning method according to the present invention can be carried out by using also other suitable measuring systems than ECT and which can detect changes in the gas stream during the soot cleaning. Such systems include e.g. optical measuring systems and other electrical measuring systems.

The dependency between each cleaner and the ECT reading is mapped. This means in practice that the amount of particles that has built up in the coverage of a cleaning device k is calculated from the ECT readings.

$$m_k = f(\text{ECT}) / T_k \quad 1$$

where :

$m_k$  = particle mass flow when cleaner k is running

$T_k$  = time elapsed between the last run of cleaning unit k

It should be noticed that the signals from all ECT antennas will be used for calculating the mass of particles that are emerged into the gas stream by cleaning unit k. In a situation where several cleaners are running simultaneously, a multivariable correlation analysis is to be applied.

The main variable that is to be optimized is the time ( $T_k$ ) between the run of each cleaning device k ( $k=1,n$ , where n is the number of cleaning devices). This procedure is fairly straightforward. A limit ( $M_{LK}$ ) for how big the  $m_k$  is to be for

cleaning is defined. The  $T_k$  is then extrapolated from the latest run of the cleaning unit  $k$ , by also noting other process variables such as gas flows, solid feeds, etc.

Besides the elapsed time between the run of the cleaning unit, also the runtime and other parameters concerning the cleaning device is to be determined in order to achieve a maximal cleaning efficiency. The object function for each cleaning device depends on the physical properties of the device and should, hence, be determined on a case by case basis.

Furthermore, it has been observed that a certain signal behavior reflects specific conditions for the particles passing the antenna matrix. For example, a positive DC signal on a normal AC level indicates a higher content of carbon in the ash flowing past the ECT antenna matrix. If the particles show a high negative DC signal on a normal AC level, the particles possesses properties that enable them to easily to stick onto the surfaces. Hence, ECT signal can be used to estimate important properties for the ash flowing in the exhaust gas channel. Please note that a high carbon in ash indicates a poor combustion and hence a risk for fouling.

The concept according to the present invention is used to optimize the soot cleaning more thoroughly. The block scheme in fig. 6 illustrates the procedure. At least partly based on ECT measurements, one can estimate one or more of the following variables: 1) a time to be elapsed between runs of cleaning units  $k$ , 2) fouling tendency of the ash, and 3) carbon content in ash. Beside said estimates, one can use one or more of the following attributes as a variable in optimization: a) data input (temperatures, steam date, etc.) from data collection system of the process, b) data base containing history from previous cleaning and results, and c) ECT measurements. According to the present invention, by combining desired values from the group of estimated variables 1-3 and variables a-c, optimization of the soot cleaning process can be made. An aim of the optimization process is to maximize the efficiency of the process, such as the combustion process, and to

minimize the costs of the cleaning process. As a result from the optimization process, one achieves information which can be used to control the cleaning sequence, time between running of cleaning devices, or the like variables for the cleaning devices.

The present invention provides an improved control for the soot cleaning process. Based on the information achieved with the optimization according to the present invention, one can e.g. define individually for each separate cleaning device different time between running and running parameters during cleaning.

While the invention has been described in the context of a preferred embodiment, it will be apparent to those skilled in the art that the present invention may be modified in numerous ways and may assume many embodiments other than that specifically set out and described above. The air/fuel optimization method and the soot cleaning optimization method can be exploited independently and thus described methods are not dependent of each other. Furthermore, it should be noted, that the soot cleaning method according to the present invention can be carried out by using also other suitable measuring systems than ECT and which can detect changes in the gas stream during the soot cleaning. Such systems include e.g. optical measuring systems and other electrical measuring systems.

### Claims

1. Method for air/ fuel control, wherein at least one of the group of primary airflow, mill parameters, and secondary airflow, is controlled using a control algorithm, which is determined by correlation analysis between ECT signals and the output and input signals of the process in order to detect dependencies, and by fuzzy modeling of the dependencies.
2. Soot cleaning optimization, wherein the optimization is based on one or more of the variables: 1) time to be elapsed between runs of cleaning units k, 2) fouling tendency of the ash, and 3) carbon content in ash, which variables are estimated from ECT measurements.

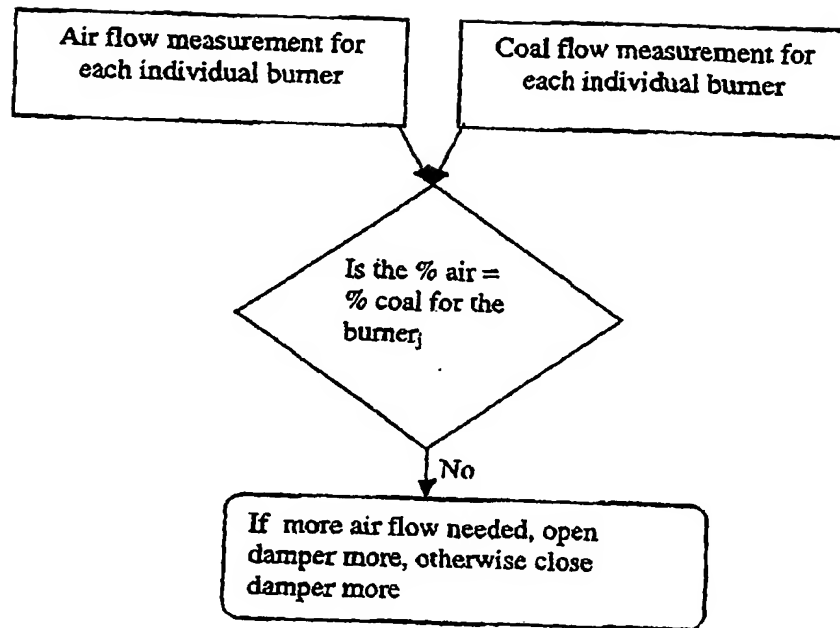


Fig. 1

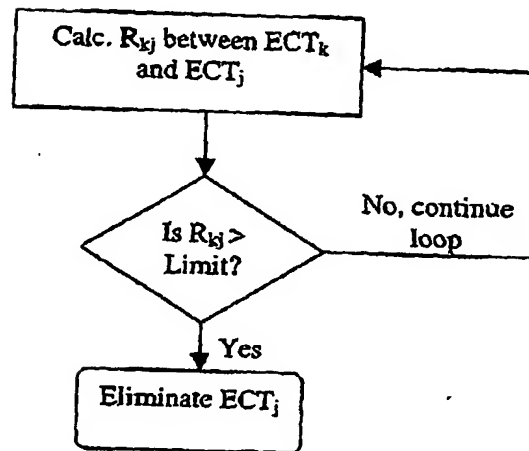


Fig. 2

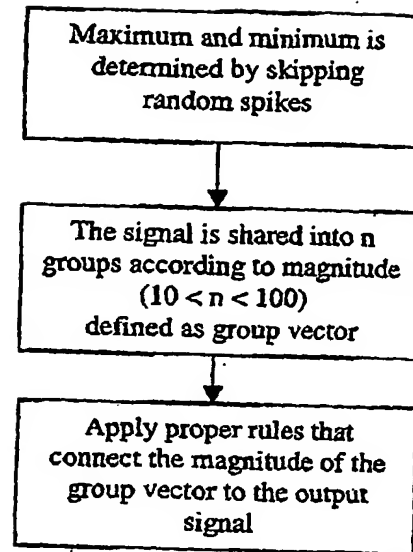


Fig. 3

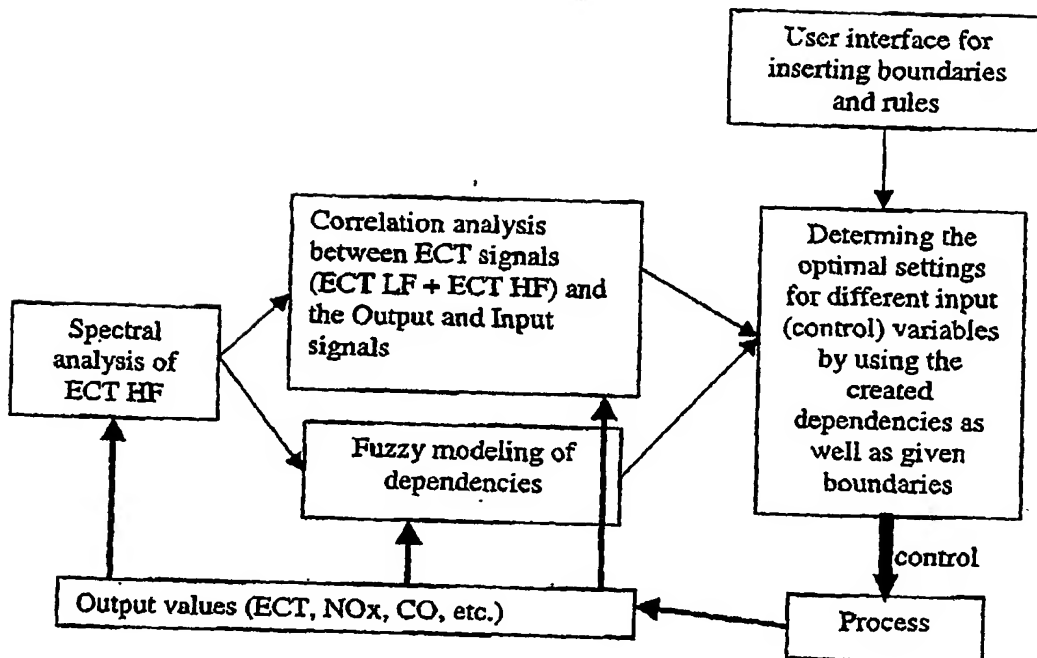


Fig. 4



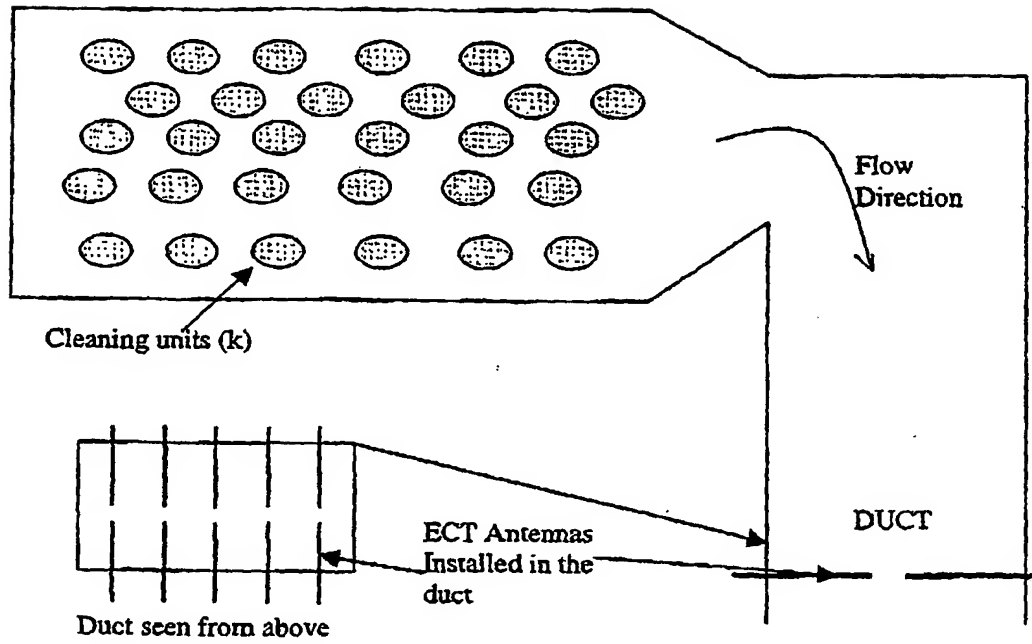
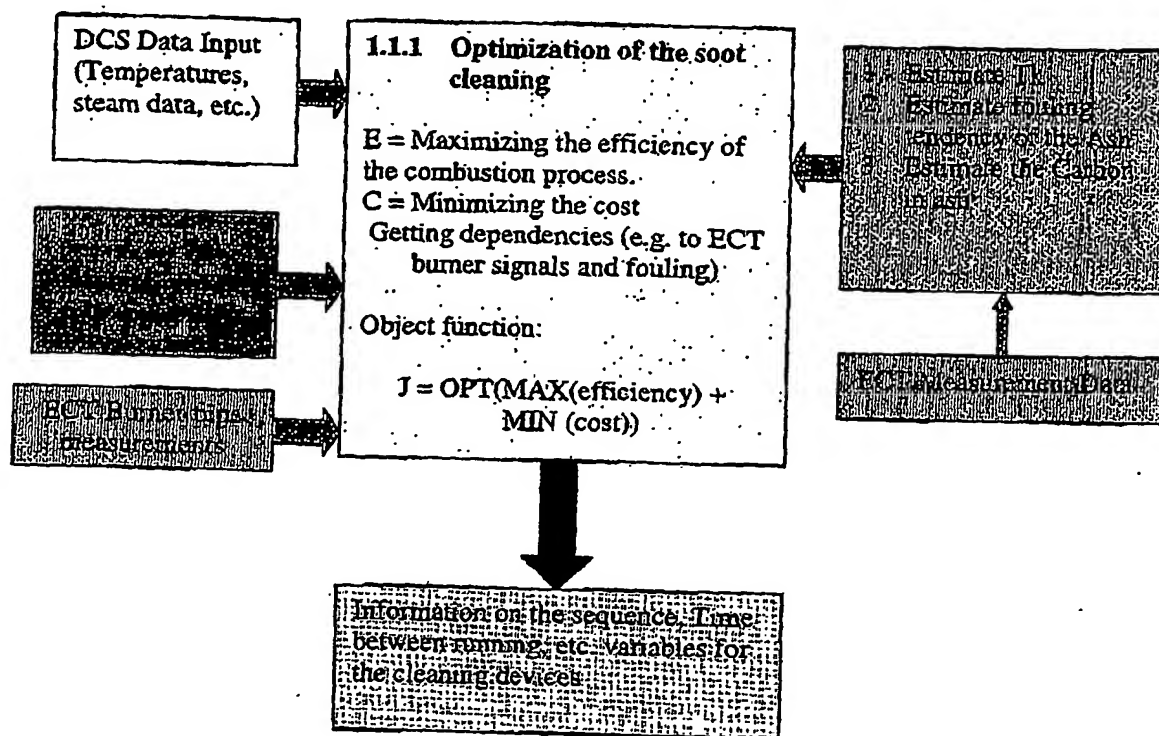


Fig. 5



where:

$T_k$  = time elapsed between the last run of cleaning unit  $k$   
 $m_k$  = particle mass flow when cleaner  $k$  is running

Fig. 6

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